Relationship Between *Aphis gossypii* (Homoptera: Aphididae) and Sticky Lint in Cotton

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J. Econ. Entomol. 95(2): 299–306 (2002)

ABSTRACT The study was conducted in the northern Texas Rolling Plains in 1999 to define the relationship between number of cotton aphids, *Aphis gossypii* Glover, and resulting contamination of cotton lint by honeydew. Whole-plot treatments were three furrow irrigation management treatments: cotton grown without supplemental irrigation (dryland), irrigated cotton with last irrigation in mid August, and irrigated cotton with last irrigation in late August. Subplots within each irrigation treatment included an untreated check, a plot treated with lambda-cyhalothrin to stimulate aphid population increase, a plot treated with lambda-cyhalothrin followed by pymetrozine after aphids began to increase, and a plot treated with lambda-cyhalothrin followed by thiamethoxam after aphids began to increase. Cotton aphids were counted on leaves picked from the top and bottom half of the plant. Cotton lint was analyzed for contamination by glucose, fructose, sucrose, and melezitose secreted by cotton aphids, and percentage leaf moisture and nitrogen and leaf sucrose concentrations were determined. The manual sticky cotton thermodetector was used to determine degree of lint stickinesss. There was a significant relationship between thermodetector counts and melezitose contamination on lint, and a melezitose concentration of 90.9 μg/g of lint was associated with a thermodetector count of 10, the threshold for sticky lint problems in textile mills. An equation was developed to estimate melezitose concentration on lint as a function of average numbers of aphids per leaf and the interaction between percentage leaf moisture and nitrogen. The number of aphids per leaf associated with a melezitose concentration of 90.9 μg/g of lint ranged from 11.1 to 50.1, depending on percentage leaf moisture and nitrogen. The threshold for sticky lint problems occurred when aphid numbers ranged between 11.1 and 50.1 per leaf after bolls open.

KEY WORDS *Aphis gosssypii*, honeydew, melezitose, thermodetector, sticky cotton, threshold

THE COTTON APHID, *Aphis gossypii* Glover, and silverleaf whitefly, *Bemisia argentifolii* Bellows & Perring [= *B. tabaci* (Gennadius) strain B], secrete honeydew that contaminates cotton lint after bolls open. Problems associated with sticky lint include higher costs of insect control, increased trash in seed cotton, special handling requirements at cotton gins, reduced efficiency at textile mills, and reduced profits (Hector and Hodkinson 1989, Ellsworth et al. 1999). Although considerable information exists on the relationship between silverleaf whiteflies and sticky lint (Henneberry et al. 1996, 2000b), there is little data on degree of sticky lint problems associated with cotton aphid populations. However, cotton aphids were reported to be responsible for the sticky cotton problem in Israel from 1983 to 1985 (Broza 1986) and in California in 1986 (Perkins and Bassett 1988). The sticky cotton problem in the Texas High Plains in 1995 (Lloyd 1997) was the result of cotton aphid honeydew and plant-produced physiological sugars on lint resulting from an early frost.

Sucrose constitutes over 90% of the carbohydrates in cotton phloem sap (Tarczynski et al. 1992). After ingesting sucrose from phloem, the cotton aphid metabolizes sucrose into several dozen sugars that are excreted in the honeydew (Hendrix 1999). Sugars in cotton aphid honeydew include glucose, fructose, sucrose, trehalulose, and melezitose and other oligosaccharides; however, melezitose constitutes 22–38% of the honeydew sugars (Hendrix et al. 1992, Hendrix and Henneberry 2000). The disaccharides sucrose in silverleaf whitefly and cotton aphid honeydews, and trehalulose primarily in silverleaf whitefly honeydew, are the stickiest sugars in honeydew and cause maximum stickiness at 0.08–0.10% sugar content in water sprays applied to cotton. Melezitose, a trisaccharide found primarily in cotton aphid honeydew, is relatively nonsticky but causes stickiness in water sprays at concentrations $\geq$ 0.60% (Miller et al. 1994). Hendrix and Henneberry 2000 reported that cotton aphid honeydew production was greatest in early afternoon, and that the longer the lint was exposed to honeydew accumulation, the greater the lint stickiness.

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0022-0493/02/0299–0306$02.00/0

The manual sticky cotton thermodetector, developed by the International Center for Agronomic Research and Development (CIRAD, Montpellier, France), is recommended by the International Textile Manufacturers Federation (ITMF) for measuring cotton lint stickiness (Perkins and Brushwood 1994). Results from the thermodetector and minicard (another ITMF-recommended test for stickiness measurement) methods are highly correlated; both detect insect sugars on cotton lint effectively, and 80–90% of cotton stickiness problems are caused by insect honeydew (Hector and Hodkinson 1989, Brushwood and Perkins 1993). However, neither method is very effective at separating the effects of plant-produced physiological sugars (glucose, fructose, and sucrose) that may be present on lint from insect honeydew sugars on lint. Plant physiological sugars alone may cause textile processing problems under certain circumstances (Hector and Hodkinson 1989, Perkins and Brushwood 1994, Henneberry et al. 2000a). Brushwood and Perkins (1993) described the procedure for measuring cotton lint stickiness potential using the thermodetector, and they reported that a reducing sugar concentration of 0.4% on lint produces a minicard rating of 1, which is near the threshold for causing sticky lint problems. A minicard rating of 1.5 was associated with a melezitose concentration of 0.6% on lint, but a mixture of sugars containing 15% melezitose produced a minicard rating of one at 0.04% sugar concentration (Miller et al. 1994). A minicard rating of 1 is associated with a thermodetector count of 10 sticky spots on a 10-g sample of lint fitted into an 11 by 25-cm template (Perkins and Brushwood 1994). Thus, a thermodetector count of 10 appears to be near the threshold for sticky lint problems caused, in part, by melezitose in cotton aphid honeydew.

The objectives of this research were to define (1) the relationship between melezitose concentration on cotton lint and thermodetector counts, and (2) the relationship between aphid numbers and melezitose concentration so that the relationships between the number of cotton aphids per leaf and the threshold for sticky lint problems could be defined.

Materials and Methods

This study was conducted for four consecutive years, 1997–2000, at the Texas Agricultural Experiment Station at Chillicothe, TX. However, rain cleansed honeydew from the cotton lint in the fall of 1997 before sticky measurements could be made, and extreme heat and drought in the summer of 2000 limited aphid population development. Instrumentation problems related to 1998 samples provided unreliable sticky data, and lint samples were not sufficient to conduct additional tests. The 1999 test provided the only complete data set related to aphid populations, sugar contamination on lint, and sticky lint readings. The cultivar TAMCOT Sphinx was planted 28 April 1999. Seeding rate was 5.7 seeds per 0.3 m of row in 102-cm row spacings, and row direction was E-W. Fertilizer was applied immediately before planting at 33.6 kg N/ha in dryland plots and 67.2 kg N/ha in irrigated plots. Subplot size was 10 rows wide by 21.3 m long.

A split-plot experimental design, arranged as a randomized complete block with three replications, was used. Whole plots were three irrigation treatments: (1) dryland—no supplemental irrigation during the growing season, (2) early termination of irrigation with last application in mid August, and (3) late termination of irrigation with last application in late August. The latter two treatments are referenced as irrigated-early termination and irrigated-late termination, respectively. Irrigation dates were 15 and 29 July and 12 August in both irrigated-early and irrigated-late termination treatments, with a final irrigation on 27 August in the irrigated-late termination treatment. Whole plots were furrow-irrigated, and ≈7 cm of water was applied at each irrigation. The outside furrows in irrigated plots, adjacent to dryland plots, were not watered to prevent seepage across the rows.

Subplots were four chemical treatments: (1) an untreated check; (2) an application of lambda-cyhalothrin (Karate EC at 0.045 g ([AI]/ha), Zeneca; Wilmington, DE) during anticipated periods of increased bollworm, *Helicoverpa zea* (Boddie), activity; (3) an application of lambda-cyhalothrin followed by an application of pymetrozine (Fulfill 50 WG at 70 g [AI]/ha, Syngenta, Greensboro, NC) when cotton aphid numbers began to rapidly increase; and (4) an application of lambda-cyhalothrin followed by an application of thiamethoxam (Actara 25 WG at 50 g [AI]/ha, Syngenta) when cotton aphids began to increase. Lambda-cyhalothrin was applied on 2 and 25 August based on the relationship between moon phase and increased bollworm moth activity (Parajulee et al. 1988), while pymetrozine and thiamethoxam were applied 8 and 17 September, respectively. Slosser et al. (2001) discussed the influence of these treatments on aphid populations.

Chemicals were applied with a John Deere Hi-Cycle sprayer (Deere, Moline, IL) with drops to provide three nozzles per row. Total solution applied was 101 liter/ha. The middle six rows within the 10-row plots were treated to minimize drift onto adjacent plots.

Aphids were sampled once per week from mid-July to late October, and samples were taken from the middle six rows of a plot. However, only the data taken on 22 and 28 September and 20 October were used in analyses. Aphids were counted on 10 leaves picked from the top and bottom half of the plant, for a total of 20 leaves sampled per plot on 22 September, but sample size was reduced to five top-half and five bottom-half leaves thereafter because of very high aphid numbers on 28 September. A leaf was picked every two to three steps along a row and visually examined. Top- and bottom-half leaves were taken from different rows within a plot. Aphids were counted individually unless numbers exceeded ≈100/leaf, when numbers were estimated by counting aphids in groups of five.

Leaf disks were cut from cotton leaves for analysis of sugar content (glucose, fructose, sucrose, trehalu-

Table 1. Mean (± SE) sugar concentration (μg/gm lint) and thermodetector counts on cotton lint on three sample dates

Date	Glucose	Fructose	Sucrose	Melezitose	Total sugars	Thermodetector
23 Sept.	415.8 ± 18.8b	750.4 ± 63.5b	84.9 ± 8.9b	147.3 ± 13.2b	1398.4 ± 98.6b	23.3 ± 2.8b
30 Sept.	560.2 ± 34.1a	1146.8 ± 84.8a	130.8 ± 17.4a	175.3 ± 15.1a	2013.0 ± 137.9a	29.2 ± 2.4a
10 Nov.	174.6 ± 8.1c	196.5 ± 14.8c	4.2 ± 2.9c	64.9 ± 1.9c	440.4 ± 21.6c	2.9 ± 0.3c
F	67.90	70.43	39.83	38.30	75.45	125.70
P	<0.001	<0.001	0.001	<0.001	<0.001	<0.001

Means within the same column followed by a different letter are significantly different; df = 2, 48 for all *F* values.

lose, and melezitose) on the same dates that aphids were counted. Leaf disk samples were taken from only untreated and lambda-cyhalothrin-treated plots in each of the three water management treatments. A leaf from the fifth mainstem node below the terminal was selected, and six disks, each measuring 0.33 cm^2 in area, were cut with a cork borer from each of two leaves per plot. If the leaf was contaminated with aphids and honeydew, it was thoroughly washed with distilled water and dried before cutting the leaf disks. The six disks from each leaf were placed into 2 ml of an 80% ethyl alcohol solution in a stoppered test tube (13 by 100 mm) and placed immediately into a cool chest containing ice. Sampling was conducted between 0900 and noon. When sampling was completed, the test tubes with leaf disk samples were stored in a freezer (−4°C). These samples were sent to the USDA-ARS Western Cotton Research Laboratory, Phoenix, AZ, for sugar analysis.

Leaf disks were extracted three times with 2-ml portions of 80% ethanol in a waterbath maintained at 70°C. The ethanol extracts were combined, brought to 10 ml volume, and a 1.0-ml aliquot was treated with powdered activated charcoal to remove phenolics and related materials (Hendrix and Peelen 1987, Hendrix 1993). After removing the activated charcoal by centrifugation, a 200 ×l aliquot of the charcoal-treated supernatant was dried at 55°C under a stream of N2. The resulting residue was suspended in water and analyzed by HPLC using a pair of Dionex PA-1 columns, an elutant consisting of sodium hydroxide and sodium acetate, and pulsed amperometric detection (Hendrix and Wei 1994).

Ten leaves from the fifth mainstem node below the terminal were collected to determine leaf moisture on the same day from the same plots that were sampled for leaf sugar content. Leaves were pulled from the stem of the plants, and the ten leaves from each plot were placed immediately into a plastic bag in a cool chest with ice. Within an hour of being picked, leaf petioles were cut off with a sharp knife, and the leaves were weighed and then oven-dried at 50°C for 48 h. Percentage leaf moisture was calculated by subtracting dry weight from wet weight, dividing by wet weight, and multiplying by 100.

The leaves that were sampled for leaf moisture content, after drying, were then used to determine percentage leaf nitrogen. Leaf nitrogen was determined using the Kjeldahl procedure (AOAC 1980) at the Texas Agricultural Experiment Station, Vernon, TX.

Open cotton bolls were pulled from 1 m of row in a uniform stand of cotton in each plot. Samples were taken on 23 and 30 September and 10 November 1999. The last harvest occurred after a plant-killing freeze; it is a common practice in this region to harvest after a freeze. Lint was picked from the burs, and a small laboratory bench-top gin was used to separate seed and lint. Lint from each plot was thoroughly mixed, and samples from each harvest date were sent to the USDA-ARS Cotton Quality Laboratory, Clemson, SC, for analysis using the manual sticky cotton thermodetector. Sticky measurements were made on three subsamples of lint from each plot on each harvest date using the methods described by Brushwood and Perkins (1993). The subsample data in each plot were averaged for analysis. Lint samples were also sent to the USDA-ARS Western Cotton Research Laboratory, Phoenix, AZ, and honeydew sugars were extracted from the lint for HPLC analysis following the procedures outlined by Henneberry et al. (2000c).

Lint samples were taken within 2 d of aphid and plant samples in September. However, the final plant samples and aphid counts were taken 20 October, because fifth mainstem node leaves and nearly all leaves on the bottom half of the plant had abscised, making it impossible to sample the types of leaves that had been selected earlier. Thus, the 20 October samples represent the only data available for correlation with lint contamination at harvest on 10 November. After 20 October, aphids were counted on available leaves in five plots once per week to 10 November to determine if there was a significant change in numbers during that time interval.

Statistical Analyses. Data were analyzed with a repeated-measures analysis of variance (ANOVA) and by linear and stepwise regression using Statistix 7 (Anonymous 2000). Main factors were irrigation treatment ($n = 3$), chemical treatment ($n = 2$ or 4), and sample date ($n = 3$). Sticky counts were transformed using $\sqrt{x + 0.5}$ before analysis, but data in tables are original scale values. Means were separated with protected least significant difference (LSD) ($\alpha = 0.05$).

Results and Discussion

Sugar concentrations on lint and thermodetector counts of numbers of sticky spots (Table 1) are shown for three sample dates in the fall, 1999. All sugars and thermodetector counts were significantly highest on 30 September and lowest on 10 November. There was 8.9 cm of rain between 8 and 31 October, which cleansed the lint of sugar contamination that occurred during late September. Aphid numbers were low through August but began increasing rapidly in early

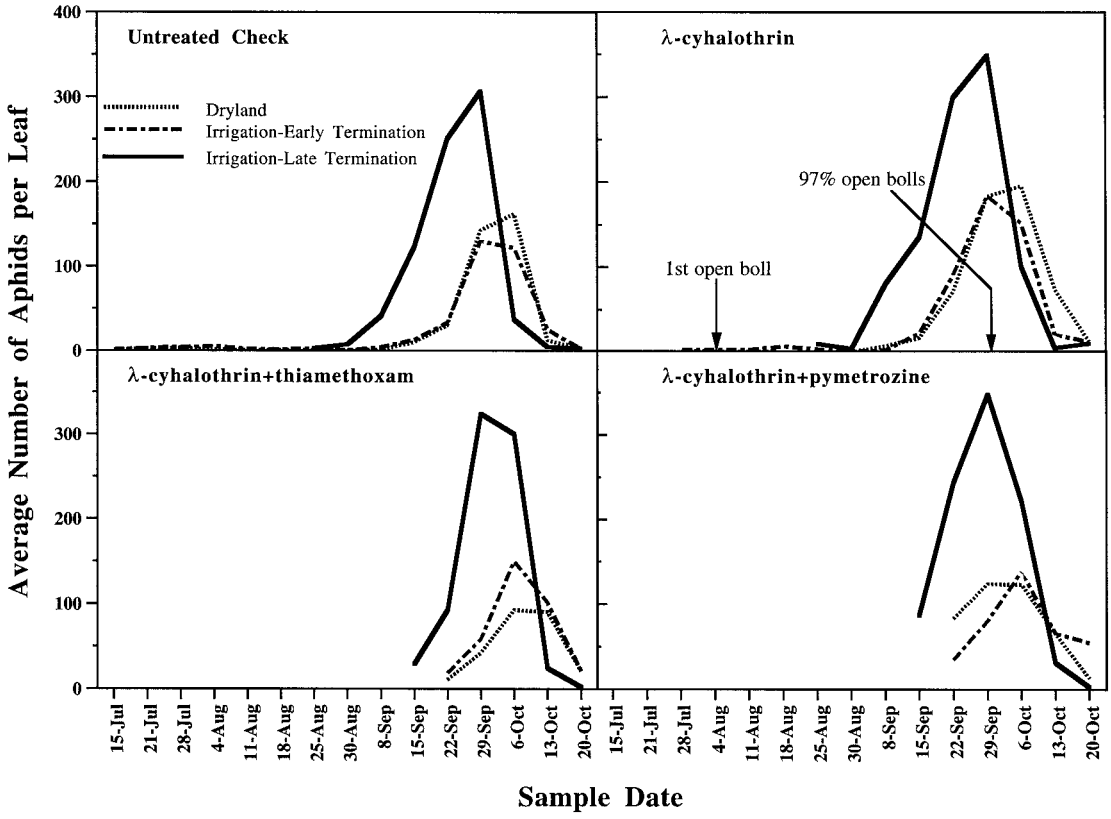

Fig. 1. Average number of cotton aphids per leaf during the growing season in three irrigation treatments and four chemical treatments.

September, and highest numbers per leaf occurred on 28 September (189.1 ± 33.0 pooled over replications, $n = 12$) just before the 30 September lint sample; aphid numbers declined after 28 September (Fig. 1). On 30 September, 96.5 ± 1.7% of the bolls were open.

Irrigation management had little influence on sugar concentration on lint (Table 2). Glucose concentration and thermodetector counts were highest in plots receiving the late irrigation on 27 August, but fructose, sucrose, melezitose, and total sugar concentrations were not affected by irrigation treatment. Glucose and sucrose concentrations were not influenced by chemical treatment (Table 3) Fructose concentration was highest in the lambda-cyhalothrin-only treatment and lowest in the lambda-cyhalothrin plus thiamethoxam treatment. Melezitose concentration and thermodetector counts were lowest in the lambda-cyhalothrin plus thiamethoxam treatment.

For melezitose, the interactions between irrigation treatment and chemical treatment and between sample date and chemical treatment were not significant ($F = 0.22$; df = 3, 18; $P = 0.965$; $F = 1.24$; df = 6, 48; $P = 0.301$, respectively). The interaction between irrigation treatment and sample date was significant ($F = 5.32$; df = 4, 48; $P = 0.001$). Melezitose concentration was highest in irrigated-late termination plots on 23 and 30 September compared with concentrations in irrigated early- termination and dryland plots, which had similar concentrations; there were no differences in melezitose concentrations among irrigation treatments on 10 November. For thermodetector counts, the interactions between irrigation treatment

Table 2. Mean (± SE) sugar concentration (μg/gm lint) and thermodetector counts on cotton lint in three irrigation treatments

Irrigation treatment	Glucose	Fructose	Sucrose	Melezitose	Total sugars	Thermodetector
Dryland	365.5 ± 28.0b	737.9 ± 81.3a	84.1 ± 14.0a	109.3 ± 7.6a	1296.8 ± 125.3a	12.7 ± 2.0b
Irrigated-early termination	345.7 ± 27.6b	546.2 ± 69.7a	46.2 ± 10.7a	106.7 ± 8.5a	1045.1 ± 112.4a	15.4 ± 2.2b
Irrigated-late termination	439.3 ± 45.5a	809.7 ± 102.2a	89.5 ± 16.9a	171.4 ± 19.7a	1510.0 ± 183.6a	27.3 ± 3.5a
F	3.40	2.43	2.84	3.20	2.67	28.36
P	0.103	0.168	0.135	0.114	0.148	0.001

Means within the same column followed by a different letter are significantly different; df = 2, 6 for all *F* values.

Table 3. Mean (± SE) sugar concentration (μg/gm lint) and thermodetector counts on cotton lint in four insecticide treatments

Chemical treatment	Glucose	Fructose	Sucrose	Melezitose	Total sugars	Thermodetector
Untreated	381.3 ± 38.0a	734.7 ± 102.6ab	72.7 ± 15.8a	137.1 ± 14.2a	1326.3 ± 164.6ab	20.1 ± 3.2a
Cyhalothrin	427.3 ± 40.3a	854.7 ± 109.2a	84.7 ± 17.2a	150.8 ± 16.9a	1517.5 ± 176.8a	22.9 ± 3.5a
Cyhalothrin + thiamethoxam	349.8 ± 40.0a	541.6 ± 93.1c	73.7 ± 19.0a	100.9 ± 10.0b	1066.1 ± 152.4b	12.1 ± 2.5b
Cyhalothrin + pymetrozine	375.6 ± 37.0a	660.7 ± 95.5bc	61.8 ± 12.3a	127.8 ± 16.6a	1226.0 ± 153.2b	18.7 ± 3.3a
F	2.32	5.53	0.55	5.65	4.35	13.69
P	0.110	0.007	0.656	0.007	0.018	<0.001

Means within the same column followed by a different letter are significantly different; df = 3, 18 for all *F* values.

and sample date and between chemical treatment and sample date were significant ($F = 9.17$; df = 4, 48; $P < 0.001$, $F = 3.44$; df = 6, 48; $P = 0.007$, respectively), while the interaction between irrigation treatment and chemical treatment was marginally significant ($F = 2.21$; df = 6, 18; $P = 0.090$). Thermodetector counts were lowest in the lambda-cyhalothrin plus thiamethoxam treatment in all three irrigation management treatments. Thermodetector counts were significantly higher in the irrigated late-termination treatment compared with counts in the dryland treatments on both 23 and 30 September, but on 10 November there were no significant differences among irrigation treatments. For the sample date by chemical treatment interaction, thermodetector counts were highest in the lambda-cyhalothrin treatment and lowest in the lambda-cyhalothrin plus thiamethoxam treatment on 23 and 30 September. There were no differences among chemical treatments on 10 November.

The relationship between concentration of each sugar on lint and thermodetector counts was explored with linear regression analysis (Table 4). While correlations between individual and total sugars and thermodetector counts were significant, the highest correlation was obtained with melezitose. A stepwise multiple regression selected only melezitose, indicating that melezitose was the primary sugar responsible for the thermodetector readings. Trehalulose was not detected in the HPLC analysis for sugars. Perkins and Brushwood (1994) indicated that the thermodetector does not effectively identify chronic sticky lint problems caused by plant physiological sugars (glucose, fructose, and sucrose).

The linear relationship between thermodetector counts (*TD*) and melezitose concentration on lint (*MC*) was

$$TD = -10.105 + 0.221(MC) \quad [1]$$

(Shapiro-Wilks W = 0.9685, $P = 0.3867$, $n = 36$, also refer to Table 4).

Values used in this equation ranged from 55.1 to 277.7 μg/g of lint for melezitose and from 1.7 to 47.7 for thermodetector counts. By setting the thermodetector count to 10, which is associated with unacceptable levels of sticky lint (Perkins and Brushwood 1994), a melezitose concentration of 90.9 μg/g of lint was estimated to be the threshold for sticky lint caused by cotton aphid infestations.

Percentage leaf nitrogen, leaf moisture, sucrose concentration, and aphid numbers varied significantly with sample date (Table 5). Leaf nitrogen was highest on 20 October and lowest on 22 September. Leaf moisture was highest on 28 September and lowest on 22 September. Leaf sucrose concentration was lower on 28 September compared with 22 September and 20 October. Aphid numbers were highest on 28 September and lowest on 20 October.

Irrigation management had a significant influence on cotton leaf variables and aphid numbers (Table 6). Percentage leaf nitrogen, leaf moisture, and aphid numbers were highest in the irrigated-late termination plots, which received a final irrigation on 27 August. During September, only 3.6 cm of rain occurred in mid-month, and aphid populations were suppressed in dryland and irrigated-early termination plots compared with irrigated-late termination plots. High aphid numbers in the irrigated-late termination treatment were related to plants with the highest moisture and nitrogen levels, as discussed by Slosser et al. (1998). Leaf sucrose concentration was not affected by irrigation treatment.

Percentage leaf nitrogen and moisture and sucrose concentration were monitored only in untreated and

Table 4. Linear regression analyses of the relationship between thermodetector counts and sugar concentration on cotton lint

Sugar	*F*	*P*	r^2
Glucose	69.56	<0.001	0.672
Fructose	81.98	<0.001	0.707
Sucrose	27.96	<0.001	0.451
Melezitose	390.77	<0.001	0.920
All sugars	92.82	<0.001	0.732

Regression format: y = a + bx where y = thermodector count and x = sugar concentration (μg/gm of lint). For all regressions df = 1, 35.

Table 5. Mean (± SE) percentage leaf nitrogen and moisture, leaf sucrose concentration (μg/cm²), and aphids per leaf on three sample dates

Date	% leaf nitrogen	% leaf moisture	Leaf sucrose	Aphids per leaf
22 Sept.	2.6 ± 0.1c	64.7 ± 0.5c	66.9 ± 6.0a	129.2 ± 28.3b
28 Sept.	2.7 ± 0.1b	68.9 ± 0.4a	21.6 ± 2.0b	215.6 ± 23.2a
20 Oct.	2.9 ± 0.0a	68.0 ± 0.3b	58.9 ± 7.8a	7.1 ± 2.0c
F	19.93	95.93	21.35	77.42
P	<0.001	<0.001	<0.001	<0.001

Means within the same column followed by a different letter are significantly different; df = 2, 24 for all *F* values.

Table 6. Mean (± SE) percentage leaf nitrogen and moisture, leaf sucrose concentration ($\mu g/cm^2$), and aphids per leaf in three irrigation treatments

Irrigation treatments	% Leaf nitrogen	% Leaf moisture	Leaf sucrose	Aphids per leaf
Dryland	2.7 ± 0.1b	65.7 ± 0.6b	41.2 ± 3.7a	73.7 ± 17.9b
Irrigated-early termination	2.6 ± 0.0b	67.6 ± 0.5a	51.4 ± 6.9a	75.2 ± 16.8b
Irrigated-late termination	2.9 ± 0.1a	68.3 ± 0.4a	54.7 ± 10.2a	202.9 ± 37.2a
F	25.72	11.73	1.22	63.23
P	0.001	0.008	0.359	<0.001

Means within the same column followed by a different letter are significantly different; df = 2, 6 for all *F* values.

lambda-cyhalothrin-treated plots, and these variables were not affected by chemical treatment (Table 7). However, aphid numbers were significantly higher in lambda-cyhalothrin-treated plots compared with numbers in untreated plots. Development of high aphid populations in response to lambda-cyhalothrin applications was reported by Kidd et al. (1996).

For leaf nitrogen, leaf moisture and aphid numbers, the interaction between sample date and irrigation treatment was significant (for nitrogen $F = 4.85$; df = 4, 24; $P = 0.005$; for moisture $F = 3.62$; df = 4, 24; $P = 0.019$, and for aphids, $F = 10.43$, df = 4, 24; $P < 0.001$). In each case the significant interaction was a result of no differences among irrigation treatments on 20 October, while values were significantly higher in the irrigated-late treatment compared with dryland and irrigated-early on 22 and 28 September. For leaf nitrogen, leaf moisture, and aphid numbers, the interactions between irrigation treatment and chemical treatment and between chemical treatment and sample date were not significant (for all analyses $F < 1.12$, df = 2, 6 or 2, 24; $P > 0.340$).

Percentage leaf moisture, percentage leaf nitrogen, and sucrose concentration in leaves were not correlated with melezitose concentration on cotton lint, and the two-way interactions between these three variables were not correlated with melezitose on lint (Table 8). However, there was a significant correlation between aphid numbers on leaves and melezitose concentration on lint. A multiple stepwise regression indicated that aphid numbers (*AN*) and the percentage leaf moisture by leaf nitrogen interaction (*%M%N*) were significantly correlated with melezitose concentration (*MC*) on lint:

Table 7. Mean (± SE) percentage leaf nitrogen and moisture, leaf sucrose concentration ($\mu g/cm^2$), and aphids per leaf in two insecticide treatments

Chemical treatment	% Leaf nitrogen	% Leaf moisture	Leaf sucrose	Aphids per leaf
Untreated	2.7 ± 0.0a	67.1 ± 0.5a	51.2 ± 6.1a	99.8 ± 22.6b
Cyhalothrin	2.7 ± 0.1a	67.2 ± 0.5a	47.0 ± 6.1a	134.7 ± 24.8a
F	0.00	0.08	1.09	6.84
P	0.981	0.789	0.337	0.040

Means within the same column followed by a different letter are significantly different; df = 1, 6 for all *F* values.

Table 8. Regression analyses of the relationship between melezitose concentration on cotton lint and different cotton leaf parameters

Equation no.[a]	Leaf parameter[b]	*F*	*P*	r^2
1	% leaf moisture (M)	0.79	0.389	0.047
2	% leaf nitrogen (N)	0.16	0.695	0.010
3	M × N interaction	0.36	0.557	0.022
4	Sucrose concentration (SC)	1.77	0.202	0.010
5	SC × M interaction	1.82	0.196	0.102
6	SC × N interaction	1.52	0.235	0.087
7	Aphid numbers (AN)	364.24	<0.001	0.958
8	M × N × AN interaction	300.22	<0.001	0.976

[a] Format for equations 1–7 is $y = a + bx$, and for equation 8, $y = a + bx_3 + bx_7$; where y = melezitose concentration on lint ($\mu g/gm$) and x = leaf parameter. For equations 1–7, df = 1, 16, and for equation 8 df = 2, 15, $n = 18$.

[b] Sucrose concentration is $\mu g/cm^2$ and aphids are avg. numbers per leaf.

$$MC = 176.660 - 0.589\,(\%M\%N) + 0.642\,(AN) \qquad [2]$$

(Shapiro-Wilks W = 0.9534, $P = 0.4812$, $n = 18$, Students *t* and associated *P* values for %M%N interaction are −3.30 and 0.005, and for aphid numbers, 24.23 and <0.001; also refer to Table 8).

For equation 2, percentage leaf nitrogen and percentage leaf moisture ranged from 2.4 to 3.0 and from 62.4 to 69.9, respectively; aphid numbers ranged from 2.2 to 348.8 per leaf. The number of aphids per leaf estimated to cause an unacceptable level of melezitose contamination on lint could be determined (equation 2) by setting melezitose concentration to 90.9 (from equation 1). At 90.9 μg melezitose, aphid estimates ranged from 11.1 per leaf at 2.5% leaf nitrogen and 63% leaf moisture to 50.1 aphids per leaf at 2.9% leaf nitrogen and 69% leaf moisture (Table 9). By inference, a thermodetector count of 10 was attained when aphid numbers range from 11.1 to 50.1 per leaf. The lower range in our calculated values agrees with the threshold range of 10–15 aphids per leaf reported by Rosenheim et al. (1995) and Godfrey et al. (2000).

An unacceptable level of melezitose contamination was attained under conditions of plant stress, as reflected in lower aphid numbers at the lower levels of either leaf moisture or leaf nitrogen. Isaacs et al. (1998) reported that honeydew produced by *B. tabaci* contained a higher proportion of trehalulose when this whitefly fed on water-stressed plants. Metabolism

Table 9. Estimated number of aphids per leaf to cause a sticky lint problem (i.e., thermodetector count of 10) at different percentages of leaf moisture and nitrogen

% Leaf moisture (%M)	% Leaf nitrogen (%N)		
	2.5	2.7	2.9
63	11.1	22.6	34.1
65	15.6	27.5	39.5
67	20.2	32.5	44.8
69	24.8	37.5	50.1

Melezitose ($\mu g/gm$) = 176.660 − 0.589 (%M%N) + 0.642 (aphids); a melezitose concentration = 90.973 is associated with a thermodetector count = 10.

of complex sugars such as trehalulose may be a mechanism of osmoregulation enabling *B. tabaci* to maintain internal water balance. Increased production of melezitose by the cotton aphid may be a similar response to stressed plants during the fall. This could explain why the threshold for aphids was lower when percentage leaf moisture and leaf nitrogen were lower (Table 9).

The linear relationship between aphid numbers (*AN*) and thermodetector counts (*TD*) is

$$TD = 6.040 + 0.121\ (AN) \qquad [3]$$

(Shapiro-Wilks W = 0.9701, $P = 0.4269$, $r^2 = 0.783$, $F = 122.48$, $P < 0.001$, $n = 36$).

When the thermodetector count was set to 10, the estimated aphid number was 32.7, which is intermediate between 11.1 and 50.1 (Table 9) and illustrates the importance of host plant condition on the amount of melezitose secreted by cotton aphids onto cotton lint. One factor that we could not investigate in detail was the influence of temperature on the aphid threshold. As indicated previously, 1999 was the only year that provided a complete data set. Observations (J. Leser, Texas Agriculture Extension Service, Lubbock, personal communication) suggest that more honeydew is excreted per aphid onto lint when fall temperatures are warmer than when temperatures are cooler.

Because thermodetector count is a function of melezitose concentration (equation 1), and melezitose concentration on lint is a function of plant quality parameters and aphid abundance (equation 2), thermodetector values can be easily estimated by substituting equation 2 into equation 1. Calculated thermodetector values provide an estimate of potential lint stickiness. Although thermodetector values calculated from equations one and two would provide best estimates, because these relationships capture the effect of both aphid abundance and plant quality parameters, the relationship between thermodetector counts and aphid numbers alone (equation 3) provides reasonable estimates of thermodetector values when plant quality parameters are not available. In our data verification using average nitrogen (2.7%) and leaf moisture (66%) values (from Table 9), equation 3 estimates of thermodetector counts deviated by 5.0% ± 1.4 (mean ± SE) compared with estimates obtained from equations 1 and 2, when calculated for aphid numbers ranging from 0 to 290 per leaf.

Linear regression analysis indicated that aphid numbers remained constant between 20 October and 10 November (slope = −0.080; $F = 1.92$; df = 1, 3; $P = 0.260$). Honeydew deposits on lint in the 10 November samples were probably not the result of accumulations from earlier aphid infestations because there was 8.9 cm of rainfall during October. We have previously observed that three applications of 0.6 cm of water, applied through a center-pivot irrigation system, will effectively cleanse honeydew contamination on exposed lint (D.R.R., unpublished data). Available evidence suggests that samples taken 20 October were adequate for comparisons with the 10 November data.

Lint contamination by aphid honeydew is generally attributed to a late-maturing crop in the fall, accompanied by aphid infestations during boll opening and insufficient rainfall to cleanse the lint. However, rain typically cleanses the lint of honeydew before harvest in the Texas Rolling Plains. In California, Rosenheim et al. (1995) have shown that rain reduces lint stickiness. Aphid numbers in the range 11–50 represent a very low threshold for development of sticky lint problems. Avoidance of the problem may be a better alternative to using insecticides to control such low numbers, considering application expenses, a potential need for multiple applications, and extended reentry intervals for further sampling and harvest. Slosser et al. (2001) reported that irrigations in late August, coupled with use of lambda-cyhalothrin for control of bollworms, consistently resulted in high aphid numbers during September when cotton bolls are opening. Irrigation management, insecticide selection, and timely harvest are key to reducing the threat of honeydew contaminated lint. If critical thermodetector values change, Equations 1 and 2 or 3 can be used to estimate aphid numbers (Table 9) associated with the threshold for unacceptable lint stickiness.

Acknowledgments

We thank Bobby Idol (Texas Agricultural Experiment Station, Vernon) for technical assistance, D. E. Brushwood (ARS, USDA, Cotton Quality Research Station, Clemson, SC), for sticky cotton analysis using the sticky cotton thermodetector, and W. E. Pinchak (Texas Agricultural Experiment Station, Vernon) for leaf nitrogen analysis. E. Hequet (International Textile Center, Lubbock, TX) and T. W. Fuchs (Texas Agricutlural Extension Service, San Angelo) provided valuable comments on an early draft of this manuscript. This research was supported by The Texas Agricultural Experiment Station (Project H-8136); Western Cotton Research Laboratory, ARS–USDA, Cotton Incorporated, (Project 97-482), Texas State Support Committee (Project 98-553TX); and by Syngenta Crop Protection, Inc.

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Received for publication 10 May 2001; accepted 14 September 2001.